PB-215 229

# A PREDICTION MODEL OF MEAN URBAN POLLUTION FOR USE WITH STANDARD WIND ROSES

Francis Pooler, Jr.

Robert A. Taft Sanitary Engineering Center
Cincinnati, Ohio

1958

DISTRIBUTED BY:

NTIS

National Technical Information Service
U. S. DEPARTMENT OF COMMERCE
5285 Port Royal Road, Springfield Va. 22151

PB 215 229

# A PREDICTION MODEL OF MEAN URBAN POLLUTION FOR USE WITH STANDARD WIND ROSES

LIBRARY
Environmental Protection Agency
5555 Ridge Ave., Cincinnati, O. 45213

Francis Pooler, Jr.
U. S. Weather Bureau Research Station
Air Pollution Engineering Research Program
Robert A. Taft Sanitary Engineering Center
Cincinnati, Ohio

[1960]

Reproduced by
NATIONAL TECHNICAL
INFORMATION SERVICE
U S Department of Commerce
Springfield VA 22151

I

# A PREDICTION MODEL OF MEAN URBAN POLLUTION FOR USE WITH STANDARD WIND ROSES


## Abstract

An empirical diffusion equation is used with an estimated inventory of $SO_2$ emissions for Nashville, Tennessee, to compute monthly mean $SO_2$ concentrations. Results are compared with patterns of concentrations obtained from a network of lead peroxide candle measurements. Reasonable agreement is found between computed and observed values; topographic effects are also indicated. Relative monthly emission rates deduced from the comparisons are used to show the effect of space heating requirements.



Details of illustrations in this document may be better studied on microfiche.

# A PREDICTION MODEL OF MEAN URBAN POLLUTION FOR USE WITH STANDARD WIND ROSES

## I. INTRODUCTION

Considerable attention in recent years has been given to describing exposures of receptors to emissions from known single sources. Very little information has been assembled pertaining to the distribution, strength, and temporal variations of the multiple sources responsible for exposures of receptors in urban areas. Consequently, while it has been possible to compute exposures as being the sum of the effects of numerous individual sources, little such work has been done. Urban exposures have been described principally by means of direct air quality measurements, or through empirical relationships expressing these measurements in terms of indices of meteorological processes (MARKEE, 1959; D.S.I.R., 1945; DAVIDSON, 1942). For both planning and control purposes, a direct means to compute concentrations is necessary, since measuring the effects of proposed alterations of existing source patterns is impossible.

As part of an air pollution study in Nashville, Tennessee, (ZEIDBERG et al, 1960), a relatively dense array of sampling locations was set up. A preliminary inventory of sulphur dioxide emissions was made to permit computation of concentration patterns for comparison with the measured data. A comparison of 24-hour values from the Nashville study has been reported elsewhere (TURNER, 1959); the work here reported is intended to test the success with which monthly mean concentrations may be computed.

## II. SOURCE INVENTORY

The source inventory was made by Dr. Harold J. Paulus, of the University of Minnesota, and consisted of an estimate of the $SO_2$ emissions in arbitrary units, for each square mile of the Nashville area. Since the preponderant source of $SO_2$ is the burning of coal, it is convenient to regard the inventory units as representing the number of tons of coal burned per day. By extrapolation of estimates of the state-wide trend of coal consumption in recent years, together with an estimate of the coal consumption by the Nashville area (KENLINE, 1957), and considering the total number of arbitrary units of the source inventory, one inventory unit is calculated to be equivalent to 1 1/3 tons of coal per day, for an annual average. Since there are several factors to be considered in converting an inventory to emissions to concentrations to measured values, these factors will not be discussed separately, but will be considered together in the comparison of calculated and observed concentrations. The inventory was intended to represent the pattern of relative emission rates for a typical heating-season day; consequently, the pattern should be altered for different heating requirements, which was taken into consideration only to the extent that no attempt was made to calculate concentration patterns for marginal or non-heating months, even though sampling measurements are available for such months.

The inventory was plotted on a rectangular grid, the grid points corresponding to the centers of the one-mile square source areas. Each source square, with an exception to be noted, was then considered as a point source located at an appropriate grid point.

## III. DIFFUSION MODEL

The vertical variance, $\sigma^2$, of the distribution of effluent from a point source was assumed to be expressible as

$$\sigma^2 = 2Lu^a t^b = 2Lu^{a-b}x^b \qquad (1)$$

where u is a representative surface-layer wind speed, t is travel time, and x, travel distance, and the coefficient L and the exponents a and b are constants to be determined.

The relationship expressed by Eq. (1), and the choice of numerical values to be used were based on several considerations. Vertical turbulence may be ascribed to two interrelated causes. Horizontal flow past surface obstacles generates turbulent motions, especially when the flow is over the rough surface of an urban area. Convective motions, aside from the mass transfer which constitutes the convective process, generate secondary vertical motions which may be regarded as turbulent elements. This convective surface turbulence, when present, generally is of greater magnitude than the mechanical turbulence due to the horizontal wind. Since surface wind speed and the intensity of convection are fairly well correlated, due primarily to the diurnal variation of both parameters, an effective vertical diffusion coefficient may be reasonably well described in terms of one of these elements only. The exponent a in Eq. (1) thus depends on the relative magnitudes of, and correlation between mechanical and convective turbulence.

The duration of individual vertical eddies should be rather small in comparison with the travel times to be considered, so that if the diffusion of a perfect gas were being described, and no

vertical variation of diffusion coefficients existed, the variance would increase at a rate proportional to travel time. In practice, however, there will exist a depletion of pollutant with time due to surface deposition; this effect may be described empirically by an increase of the apparent vertical diffusion coefficient with time. The vertical mass transfer by convection will also cause a depletion of surface pollutants, and may likewise be described by an increasing apparent diffusion coefficient. An effective value of the exponent b should therefore be greater than unity under most circumstances.

The choice of effective mean values of the exponents a and b will depend on a proper weighting of instantaneous values according to their effects on surface concentrations, as well as on the relative frequency with which various meteorological conditions are observed, on the interrelationships between meteorological parameters, on the surface roughness, and on the travel times being considered. For Nashville, for the heating, or winter season, for travel distances measured in miles, and for determining monthly mean concentrations, numerical values of $a = 0.6$ and $b = 1.5$ were chosen. Somewhat different values would be chosen for other applications.

The value of the coefficient L was obtained by assuming, with the above values for a and b, that with a wind of 5 m/s, the mean plume would have a depth (taken as $2\sigma$) of about 60 m at a travel distance of 1 km., or $L = 0.06\ m^{1.4}\ sec^{-0.9}$.

The relative concentration at ground level from a continuous point source at height h, assuming the vertical distribution Gaussian with variance $\sigma^2$, reflection from the surface, and mass continuity,

and assuming uniform horizontal distribution over an arc of length $1/8\pi x$ (the length of arc of the sector represented by 1 point of a 16-point compass at a distance x) is given by

$$\frac{\chi}{Q} = \frac{2e^{-\frac{h^2}{2\sigma^2}}}{(2\pi)^{0.5}(1/8\pi x)u\sigma} = \frac{8e^{-\frac{h^2u^{0.9}}{4Lx^{1.5}}}}{\pi^{1.5}L^{0.5}u^{0.55}x^{1.75}} \qquad (2)$$

Expressing distance in units of miles, s, substituting numerical values for $\pi$, L, and h, choosing an effective mean value of 30 meters for h,

$$\frac{\chi}{Q} = \frac{1.435\times10^{-5}e^{-\frac{0.0581u^{0.9}}{s^{1.5}}}}{u^{0.55}s^{1.75}} = g_{u,s} \qquad (3)$$

Choosing a representative wind speed for each Beaufort wind speed class (Table I), the relative concentration for winds of a given speed class as a function of distance ($g_{u,s}$) can be calculated. The mean relative concentration at distance s and direction $\theta$ from a single source, $\left(\frac{\chi}{Q}\right)_{s,\theta}$ is given by

$$\left(\frac{\chi}{Q}\right)_{s,\theta} = \sum_u f_{u,\theta} g_{u,s} \qquad (4)$$

where $f_{u,\theta}$ is the fractional frequency of winds of speed u and direction $\theta$.

Eq. (4) was used to provide relative concentrations along the center lines of the wind direction sectors. Concentrations at intermediate directions were obtained by linear interpolation between

adjacent directions. More sophisticated interpolation formulae, which can be developed by assuming a more realistic instantaneous horizontal plume distribution, and assuming a continuous function for the probability of winds from an infinitesimal sector width, are not justified in view of the uncertainties of the necessary assumptions, and in view of the approximations represented by the observations themselves.

The contribution from the source square centered at the grid origin was calculated by assuming the source to be a circular area source of uniform emission strength, and of area one square mile. The concentration at the center of the circle is independent of wind direction and is given by

$$\frac{\chi}{Q} = \int \frac{2e^{-\frac{h^2}{2\sigma^2}}}{A(2\pi)^{0.5}u\sigma}dx = \frac{0.889\times10^{-4}}{u^{0.55}}\int_0^{908} \frac{e^{-\frac{3750u^{0.9}}{x^{1.3}}}}{x^{0.75}}dx = g_{u,o} \qquad (5)$$

A is the number of square meters per square mile, and the integration limit, 908 m, is the radius of a one square mile circle. The mean concentration is the summation of the concentration for each wind speed ($g_{u,o}$) times the fractional frequency of winds of that speed ($f_u$),

$$\left(\frac{\chi}{Q}\right)_o = \sum_u f_u g_{u,o} \qquad (6)$$

The wind speed and direction frequencies used in Eq. (4) and (6) were monthly summaries of hourly observations taken at the Nashville Airport, Berry Field (U. S. WEATHER BUREAU). These data were examined for odd-even bias, which, if sufficient, was removed by equalizing the total number of observations from odd and even directions and adjusting

the number of observations for the speed classes from each direction to yield the de-biased total frequency from that direction. Hours of reported calm were then assigned to the 16 directions in the 0-3 mph classification in proportion to the de-biased frequencies of winds of 0-7 mph.

A "diffusion" grid was then plotted, showing the relative concentrations from grid points at one-mile intervals to the point at the grid origin.

The calculated value of concentration for a point was obtained by centering the "diffusion" grid on the point of the source grid for which concentration was to be calculated, multiplying the pairs of numbers at the grid points and summing the products. Hand calculations were made for a number of points for purposes of comparison, but the bulk of calculating work was accomplished by programing the calculations for an IBM 650 computer. The values obtained from the computer were then plotted on a map of the Nashville area and isopleths of calculated concentration drawn. The resultant patterns for the various months calculated did not differ appreciably from each other. The pattern for each month resembled a smoothed source inventory map. An example for December, 1958, is shown in Figure 1.

## IV. MEASURING NETWORK

Observed mean monthly $SO_2$ concentrations were obtained from a network (Fig. 1) of 123 sampling sites. Lead peroxide candles were exposed in louvered shelters for monthly periods, then analyzed chemically to determine the amount of sulphate formed. The principal reaction is presumed to be $PbO_2 + SO_2 \rightarrow PbSO_4$, although any $SO_3$ or $SO_4^=$ should add to the sulphate determination (TABOR, 1959). The analytic results were expressed as milligrams of $SO_3$ per square decimeter per day.

Observed patterns for the five principal heating months were drawn. Except for a proportional variation at all sites, the patterns for all months are quite similar, so that the pattern of 5-month average concentrations was drawn (Fig. 2), thereby eliminating some of the apparently random month-to-month variations at individual stations. The observed pattern shows similarity to the predicted pattern, but with more irregularities and distortions.

## V. COMPARISON OF CALCULATED AND OBSERVED CONCENTRATIONS

To convert the calculated relative concentration values to the measurement units, a conversion factor, C, was calculated, given by

$$C = 1.065 \frac{mpr}{n} \qquad (7)$$

where m is the ratio of the average coal consumption rate during a given month to the annual average consumption rate;

p is the percentage (by weight) of sulphur in the coal;

r is the proportion emitted to the atmosphere as $SO_2$;

n is the volumetric $SO_2$ concentration, in pphm, corresponding to a sulphation rate of 1 mg. $dm^{-2}$ $da^{-1}$.

The numerical coefficient, 1.065, was calculated for a temperature of 44.2°F, and a pressure of 995 mb, which are approximately the heating season average values for Nashville. It includes the factor, 1 1/3 tons per day per inventory unit, previously derived. The factor C, when multiplied by relative concentrations times $10^4$, yields the sulphation rate in mg. $dm^{-2}$ $da^{-1}$. The proportion r and the conversion factor n are defined above in terms of $SO_2$. It would be more correct to define

both in terms of the sulphur oxides (including combined forms) which may react with the lead peroxide candles; discussion in terms of $SO_2$ alone is primarily a matter of convenience.

Estimates of p, r, and n can be made (Table II) and a value of m for each month can be obtained from a consideration of all months' data, as will be done below. The combined uncertainty from all these parameters is too great to permit a reliable calculation of the conversion factor C, and therefore an empirical conversion factor was determined for each month from a comparison of observed and calculated concentrations. For each sampling site, a calculated concentration was determined by interpolation from the isopleths drawn (e.g., Fig. 1). A graph was plotted of observed vs. calculated concentrations, and a linear regression line computed by the least squares method (Fig. 3). If there were no bias in either the calculated or observed values, the slope of the regression line would be the empirical conversion factor desired, and the intercept with the ordinate would represent the average exotic contribution--exotic here meaning from sources not included in the inventory. Evidence of some bias, and its probable effect, will be discussed below.

For each month, the observed concentrations were expressed as percentages of the values predicted from the regression equation for that month. These percentages were plotted and isopleths drawn to provide a comparison of the patterns of calculated with observed concentrations. The percentage isopleths for all months showed very similar patterns, and so the results were combined for all five months by calculating and plotting an average percentage, the average of the five monthly percentages, for each station (Fig. 4).

The more elevated locations, particularly where the slope of the land is down toward the effective sources for that location, showed higher than predicted concentrations. In low areas, concentrations were generally lower than predicted, particularly if higher terrain separates the location from the effective sources. Concentrations were quite consistently below predicted along the Cumberland River. From limited comparisons of sulphation rates of the lead peroxide candles with mean volumetric sulphur dioxide concentrations, it appears that higher wind speeds increase the sulphation rate. Some of the association between topography and relative concentrations should be a consequence of an association between topography and wind speed, but it is felt that the greater part of the apparent relationship is a real topographic effect on concentrations themselves.

The indicated topographic effect is physically plausible, although it would be extremely troublesome to represent mathematically. It also, in this case, introduces a difficulty in determining an empirical conversion factor. Some correlation exists between calculated and relative concentrations (cf. Figs. 1 and 4) such that low values of both tend to occur together. Because of this bias, the numerical coefficients obtained by regression analysis should be interpreted with caution. To provide an indication of the significance of this bias, another regression line was computed, using only data from stations at ground elevations of between 450 and 550 ft. MSL that were not separated from the principal contributing sources by terrain exceeding 550 ft. in elevation. Slightly less than half the sampling sites were retained in this selection, which represents an approximation to the

level plain over which mathematical diffusion conventionally takes place. For December, the ordinate intercept was increased from 0.060 to 0.151, and the slope constant slightly decreased, from 1.275 to 1.186, by using the selected data. There is apparently additional bias in the data, for the exotic component, based on the distribution of observed values (e.g., Fig. 3) and on the locations at which the minimum values occurred, is about 0.30 mg., or twice the value determined from the supposedly de-biased sampling data. The value of the empirical conversion factor (the slope) appears to be a relatively stable statistic; about the same proportionate change was also found for other months examined. The slope constants based on data from all stations were adopted as representing the empirical conversion factors for different months since a more reliable statistic should be expected from the larger number of data. The values adopted appear to slightly overestimate the conversion factors because of sampling bias.

To determine the significance of heating requirements on emission rates, the empirically determined conversion factor ($C_r$) was plotted as a function of degree-days (Fig. 5). For the five months' data used, a good linear relationship exists. Conversion factors for additional months could be obtained by the same rather lengthy procedure as was done for the five principal heating months, but it is probable that the change of relative emission patterns would invalidate such computations. A simpler method was therefore devised and is believed to provide results which are of comparable validity to those that might be obtained by the more involved procedure.

A simple nondirectional monthly diffusion index was obtained from Eq. (4) and (6). A proportionality constant, equal to the sum of concentrations at six selected stations in the region of highest concentrations divided by the index value times the regression line slope value, was computed for each of the five heating months, and the five numbers averaged to obtain a single constant (Table IIIa). The conversion factor for each of several additional months was then estimated as being equal to the 6-station total concentration divided by the product of the proportionality constant times the diffusion index value for that month (Table IIIb).

It may be noted that the linear trend of emissions with degree-days is not sustained through the transitional months. It is likely that the autumn increase and the spring decrease of emissions is more a reflection of the number of sources operating than of the emission rates of operative sources; the relative emission rate for no heating requirements from the regression line (Fig. 5) is evidently not the minimum emission rate for the area, but is perhaps the minimum emission rate with all sources operating.

Assuming that the conversion factor for the months of no heating requirements is that computed for September, the relative monthly emissions for a complete year are known, and therefore the parameter m in Eq. (7) can be computed (Table IV). Values for months in different years should differ somewhat from the values for the particular year computed, aside from any new sources or changes in types of fuel consumed by existing sources, because of differing heating requirements.

The indicated annual variation of emissions is undoubtedly larger than would be found in most urban areas. One of the criteria by which Nashville was selected as a study area was that there be a large annual variation of "pollution."

Since the parameter m is defined as the ratio of the daily average consumption (or emissions) during a given month to the annual daily average, the ratio C/m will be the same for all months and is simply the average of the 12 monthly values of C, or 0.576. This value is about 15 percent greater than the "best estimate" value calculated (Table II). The agreement may be closer if the effect of sampling bias is considered, and if the small contributions to $SO_2$ emissions from sources other than the burning of coal are included.

This apparent agreement may be fortuitous, however. If all calculated concentrations were in error because of a wrong choice of the mean diffusion coefficient, and a compensating error of estimate were made in computing the conversion factor, the results would be in agreement, but in error. Therefore, the over-all accuracy of the diffusion equation cannot be determined to any greater precision than that to which the conversion factor can be calculated.

A number of adjustments are possible that would result in closer agreement between computed and observed concentrations. Such adjustments are not necessarily better assumptions, however. The source inventory is of a preliminary nature and should be expected to be in error in a few important particulars. The diffusion equation cannot adequately describe spatial variations of diffusion, nor can the simple utilization of the equation take into account spatial variations

of transport. Also, the influence of nearby sources is greatly oversimplified by the assumed source distributions. Some divergence of observed from computed concentrations is therefore to be expected; the divergence indicated is of insufficient magnitude to make a recomputation of relative concentrations feasible, in view of the many sources of possible error. For computing concentrations in the Nashville area, the regression equations for the five months analyzed provide values that are satisfactorily close to observed values. One-half of the observed concentrations were between 80 and 125 percent of predicted values; less than 1/20 of the observed values differed from predicted by more than a factor of 2, with many of these being apparently erroneous data. A subjective modification of computed concentrations to take into account topographic effects would permit even closer estimates of actual concentrations to be made.

References

DAVIDSON, W. F., (1942) Monthly Weather Review 70, No. 10, 225.

D.S.I.R., (1945) Atmospheric Pollution in Leicester. HMSO, London.

FORAN, M. R., GIBBONS, E. V., and WELLINGTON, J. R., (1958) Chemistry in Canada 10, No. 5, 33.

KENLINE, P. A., (1957) Appraisal of Air Pollution in Tennessee. U. S. Public Health Service, Cincinnati, Ohio.

MARKEE, E. H., Jr., (1959) American Industrial Hygiene Association Journal 20, No. 1, 50.

MEADE, P. J., and PASQUILL, F., (1958) International Journal of Air Pollution 1, Nos. 1 and 2, 60.

SELVIG, W. A., and GIBSON, F. H., (1956) Analyses of Ash from United States Coals. Bureau of Mines Bulletin 567. GPO, Washington.

TABOR, E. C., (1959) Personal Communication.

TURNER, D. B., (1959) A Simple Diffusion Model for an Urban Area. Paper presented at Joint AMS-AGU meeting, Washington, May, 1959.

U. S. WEATHER BUREAU. Local Climatological Data and Supplement. (Issued Monthly), Asheville, N. C.

ZEIDBERG, L. D., et al., (1960) Air Pollution and Health: General Description of a Study in Nashville, Tennessee. Paper to be presented at the Air Pollution Control Association meeting, May, 1960, Cincinnati, Ohio.

TABLE I. WIND SPEEDS CHOSEN FOR BEAUFORT SPEED CLASSES

| Wind speed (mph) | 0-3 | 4-7 | 8-12 | 13-18 | 19-24 | 25-31 |
|---|---|---|---|---|---|---|
| Representative speed (m/s) | 0.9 | 2.5 | 4.5 | 6.9 | 9.6 | 12.5 |

TABLE II. ESTIMATES FOR CALCULATING CONVERSION FACTOR $C = 1.065 \frac{\sqrt{pr}}{n}$

| Parameter | "Best Estimate" | Probable Error Ratio[a] |
|---|---|---|
| $p$[b] | 2.5 | 1.20 |
| $r$[c] | 0.75 | 1.15 |
| $n$[d] | 4.00 | 1.50 |
| Constant | 1.065 | 1.20 |
| $C/m$ | 0.499 | 1.65 |

(a) A probable error ratio, analagous to the usual linear probable error, is here used because the parameters are multiplied, not added. For the parameter n, for instance, it is assumed that the probability is 0.50 that the true value of n is within a factor of 1.50 of 4.00, i.e., between 2.67 and 6.00.

(b) From analyses of coal from SELVIG and GIBSON (1956).

(c) Estimated.

(d) From FORAN, et al (1958); D.S.I.R., (1945); MEADE and PASQUILL (1958); and limited analyses of Nashville data.

TABLE IIIa. COMPUTATION OF MONTHLY PROPORTIONALITY FACTOR F

| Month | $O_6$ | $I_d$ | $C_r$ | F |
|---|---|---|---|---|
| Nov., 1958 | 750 | 307 | 0.812 | 3.01 |
| Dec., 1958 | 1094 | 299 | 1.275 | 2.87 |
| Jan., 1959 | 1035 | 285 | 1.326 | 2.74 |
| Feb., 1959 | 864 | 292 | 1.091 | 2.71 |
| Mar., 1959 | 719 | 248 | 0.968 | 3.00 |
| Mean | - | - | - | 2.87 |

TABLE IIIb. ESTIMATES OF CONVERSION FACTOR, $C_a$, FOR ADDITIONAL MONTHS

| Month | $O_6$ | $I_d$ | F | $C_a$ |
|---|---|---|---|---|
| Sept., 1958 | 135 | 391 | 2.87 | 0.12 |
| Oct., 1958 | 414 | 429 | 2.87 | 0.34 |
| Apr., 1959 | 351 | 246 | 2.87 | 0.50 |
| May, 1959 | 118 | 332 | 2.87 | 0.12 |

$O_6$ = sum of mean daily sulphation rates, in $10^{-2}$ $MgSO_3$ $dm^{-2}$ $da^{-1}$, for stations 59, 60, 61, 69, 70, and 71.

$I_d$ = monthly diffusion index value = $\sum_u f_u (g_{u,o} + 2 g_{u,4}) \times 10^8$.

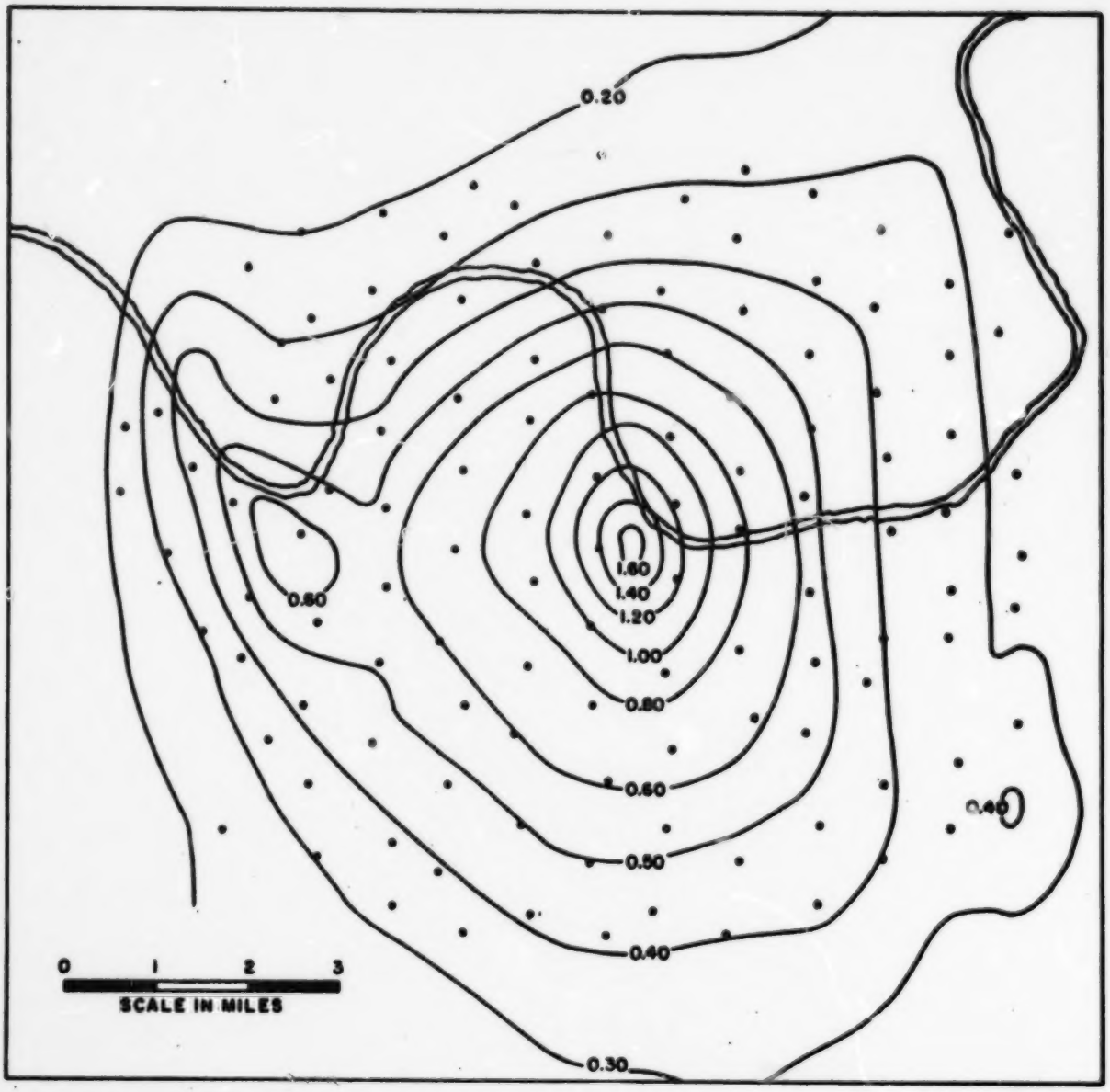
$C_r$ = empirically determined conversion factor from regression equation.

$F = O_6/I_d C_r$

$C_a = O_6/I_d F$

TABLE IV. VALUES OF m, RATIO OF MONTHLY AVERAGE DAILY $SO_2$ EMISSION RATE TO ANNUAL DAILY AVERAGE RATE, NASHVILLE

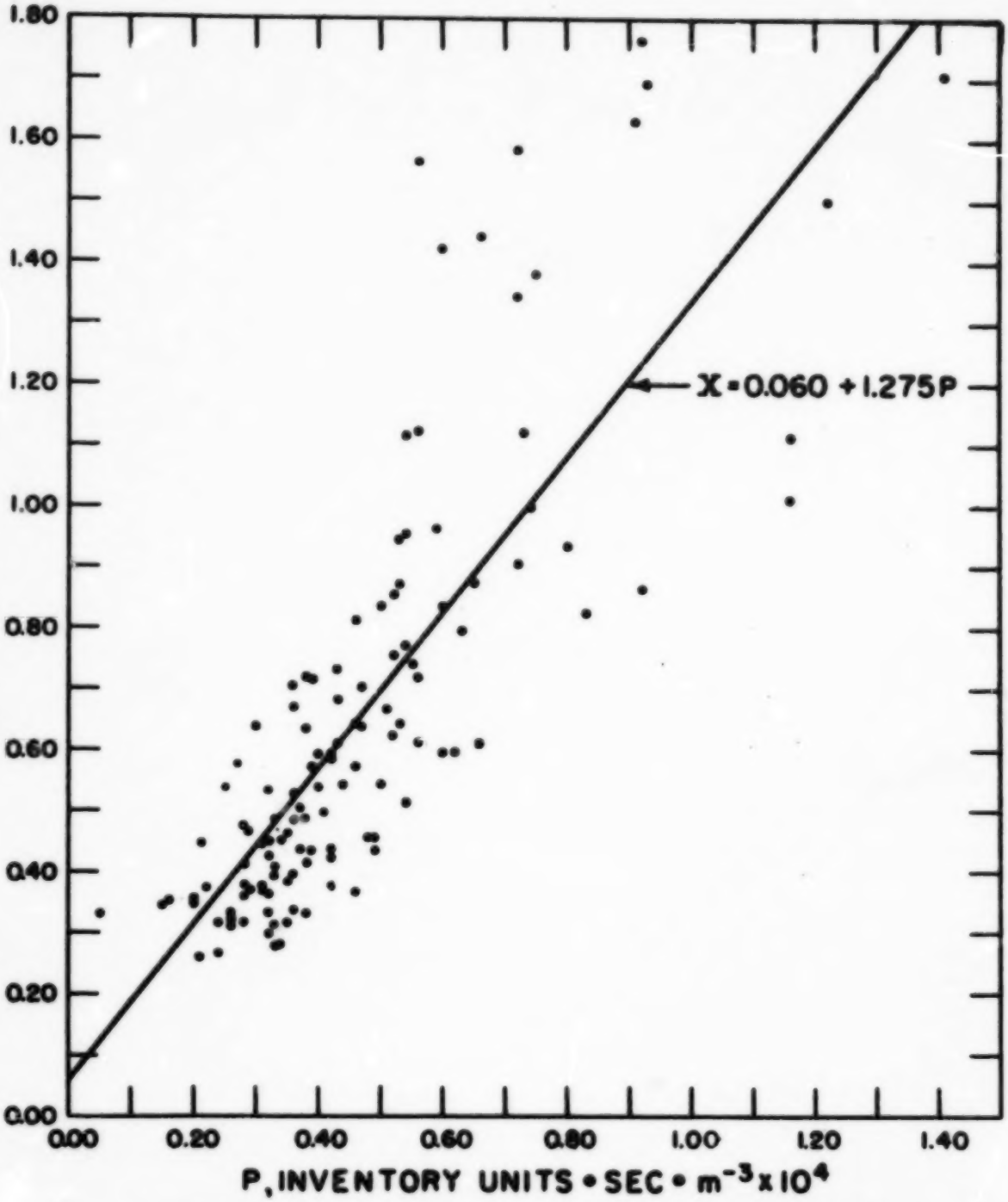
| Month | m | Month | m |
|---|---|---|---|
| Jan. | 2.30 | July | 0.21 |
| Feb. | 1.90 | Aug. | 0.21 |
| Mar. | 1.68 | Sept. | 0.21 |
| Apr. | 0.86 | Oct. | 0.58 |
| May | 0.22 | Nov. | 1.41 |
| June | 0.21 | Dec. | 2.21 |




NASHVILLE SAMPLING STATION NETWORK, AND CALCULATED MEAN $SO_2$ CONCENTRATIONS, IN UNITS • SEC • $M^{-3}$ • $10^4$, FOR DECEMBER, 1958

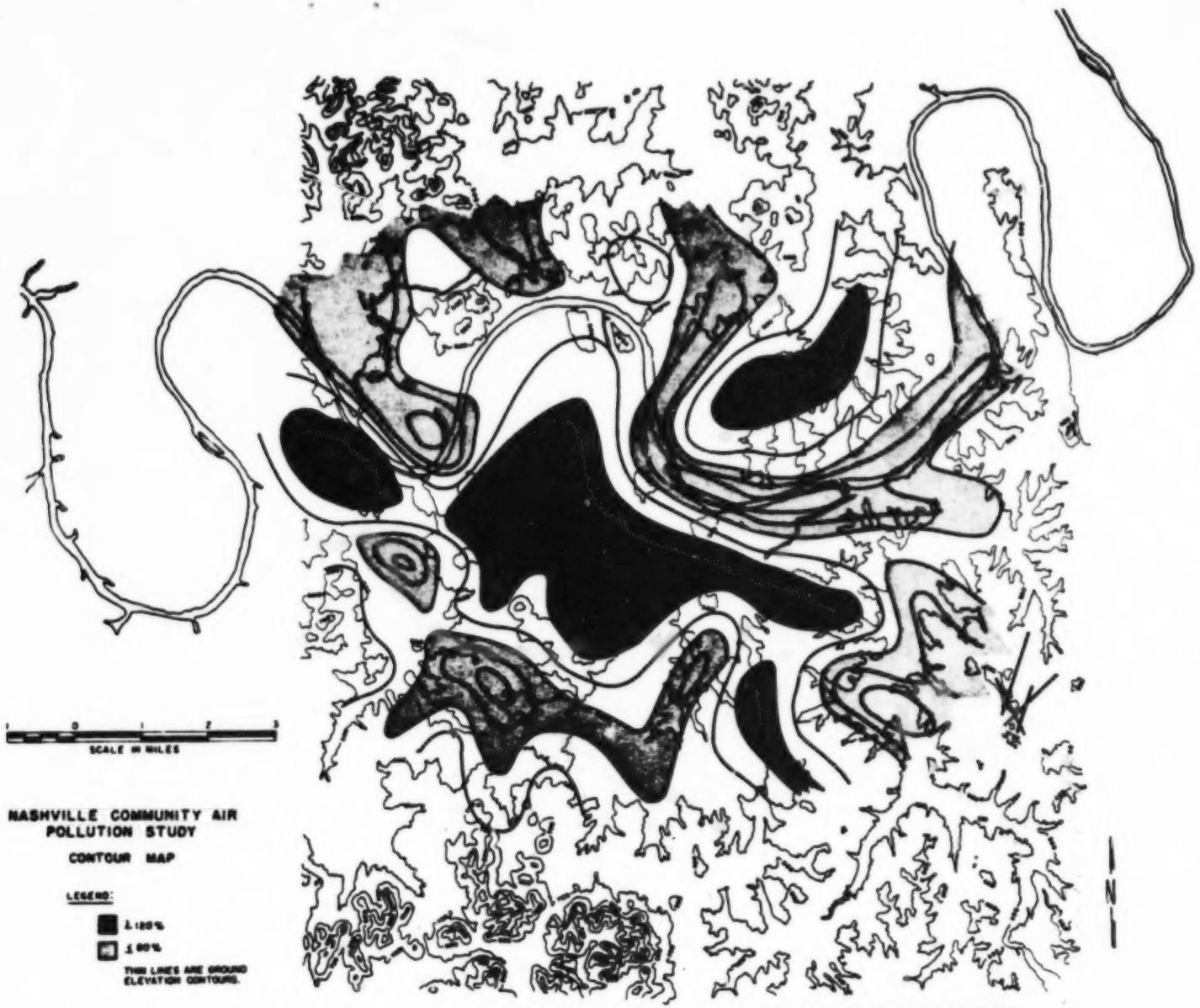
Figure 1

MEAN DAILY SULPHATION RATE OF $PbO_2$ CANDLES IN mg $SO_3/dm^2/day$
NASHVILLE, NOVEMBER 1958 - MARCH 1959
Figure 2




**OBSERVED vs. PREDICTED MEAN $SO_2$ CONC.**
**NASHVILLE, DECEMBER 1958**

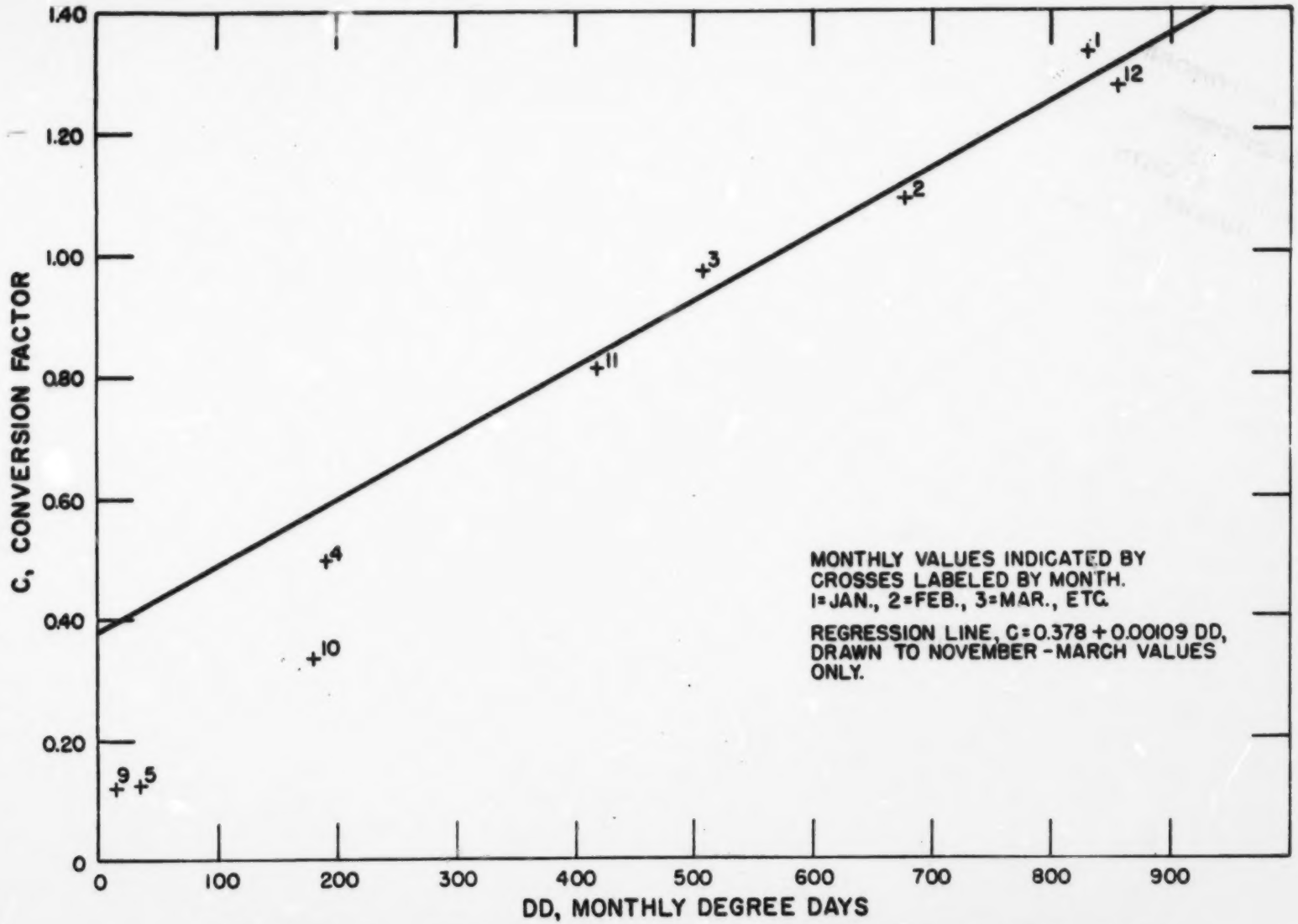
Figure 3




OBSERVED $SO_2$ CONCENTRATIONS AS PERCENT PREDICTED
NASHVILLE, NOVEMBER 1958–MARCH 1959

Figure 4

Reproduced from best available copy.




CONVERSION FACTOR, COMPUTED TO OBSERVED CONCENTRATIONS
VS. 30-DAY DEGREE DAY TOTALS
NASHVILLE, SEPTEMBER 1958 - MAY 1959

Figure 5